2024 Los Angeles Regional Science Olympiad Tournament

Astronomy C

Exploring the World of Science

Directions:

- Each team will be given **50 minutes** to complete the test.
- There are two sections: **§A** (Stellar Formation & Evolution) and **§B** (Exoplanets).
- You may **neatly** take apart your test booklet, image sheet, and answer sheet.
- Follow the rounding instructions for questions that require a numerical answer.
- Tiebreakers, in order: §A4, §A11, §B16–23, §A12–15, §B1–14, §A33, §B25.
- Best of luck! And may the stars align.

Section A: Stellar Formation & Evolution

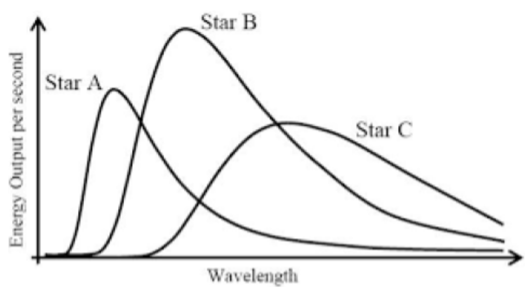
Use the image sheet to answer the following questions. Unless otherwise specified, each question is worth one points, for a total of 36 points.

"Astronomy compels the soul to look upwards and leads us from this world to another"
(Plato, 427–347 BCE)

1. Which of the following is the most influential feature in determining the lifespan of a star?
   A. Metallicity
   B. Mass
   C. Rotational speed
   D. Apparent magnitude

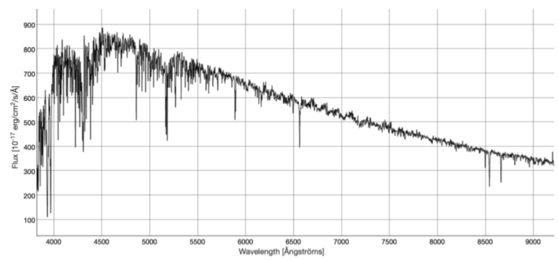
2. Generally, as a star's temperature increases, how will its color change?
   A. It becomes redder.
   B. It becomes bluer.
   C. It slowly disappears from the sky.
   D. There is no relationship between temperature and color.

3. Compare the following blackbody spectrum of three objects. Which of these objects would be hottest?



   A. Star A
   B. Star B
   C. Star C
   D. We don't have enough information.

4. [2 pts] A (real) spectrum of a star is shown below. What are two methods that we could use to determine the temperature of this star from its spectrum? (Select two answers)



   A. Compare it to a theoretical spectrum of this star to find the redshift, then use Hubble's law.
   B. Fit a Planck model to the spectrum in order to find total stellar flux.
   C. Apply a Gaussian filter, identify the peak of the curve, and use Rayleigh-Jeans law.
   D. Look at spectral lines to determine spectral class.
   E. Estimate the blackbody spectrum, and use Wien's law.
   F. Compute the area under the curve, and use Stefan-Boltzmann law.

For the next five (5) questions, consider the H-R Diagram in Image 1.

5. Which of these points shows the brightest star?
   A. Point A
   B. Point B
   C. Point C
   D. Point D
6. Which of these letters lands on the main sequence?
   A. Point A
   B. Point B
   C. Point C
   D. Point D
7. A star at which of these points is a pre-main sequence star?
   A. Point A
   B. Point B
   C. Point C
   D. Point D
8. A star at which point would have the largest B-V color index?
   A. Point A
   B. Point B
   C. Point C
   D. Point D
9. What type of object lies at point B?

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10. In a galaxy, star formation occurs ________.
    A. in the central black hole.
    B. in globular clusters in the halo.
    C. outside of the galaxy, in the intergalactic medium.
    D. in dense molecular clouds.

For the next five (5) questions, consider the deep-sky object shown in Image 2.

11. Which object is depicted in this image?

For each of letter in the image, match it to the following features in the nebula. (A–D)

12. [0.5 pts] Old, evolved background star
13. [0.5 pts] Interstellar dust
14. [0.5 pts] Cluster of young stellar objects
15. [0.5 pts] Young, hot star

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16. What objects are responsible for ionizing gas in HII regions?
    A. Nearby supernovae
    B. Dying stars shedding their outer layers
    C. Young, massive stars
    D. Bremmelstrung emission
17. As particles in a molecular cloud collapse, they lose gravitational potential energy. What is the primary way this cloud also changes in order to satisfy the conservation of energy?
    A. The particles in the center of the cloud begin to rush outward.
    B. A massive quantity of neutrinos are released.
    C. The particles begin to speed up and collide, increasing the temperature.
    D. Gravitational waves carry away this lost gravitational potential energy.
18. As the cloud collapses, it spins, and the cloud flattens out. This forms which of the following structures in a protostar?
    A. Accretion disk
    B. Dusty envelope
    C. Bipolar outflow
    D. Herbig-Haro object

For the next two (2) questions, consider the protostar depicted in Image 3.

19. How are the two circled regions formed?
    - A. Large clumps of interstellar dust collapsing.
    - B. Outflows from a protostar colliding with the interstellar medium.
    - C. Long vortices from a protostar pulling in material from farther away in the cloud.
    - D. Gravitational waves emitted by protostar accretion causing compression in the surrounding material.

20. What are these objects called?

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21. T Tauri stars form into ______ stars, whereas Herbig Ae/Be stars form into ______ stars.
    - A. Intermediate Mass/Low Mass
    - B. High Mass/Low Mass
    - C. Low Mass/Intermediate Mass
    - D. High Mass/Intermediate Mass

Image 4 shows the evolutionary transition from a protostar to a T Tauri star.

22. How does the temperature of the central object change during this transition?
    - A. The temperature of the object stays roughly the same.
    - B. The temperature of this object increases.
    - C. The temperature of this object decreases.
    - D. The change in temperature of this object is completely unpredictable.

23. How does the envelope in the protostar phase get removed during the T Tauri phase?
    - A. It is pushed away by the strong magnetic field.
    - B. It all gets pulled into the accretion disk.
    - C. The central star goes supernova, which clears out all of the surrounding material.
    - D. Strong stellar winds from the forming star sweep away the envelope.

24. What do broad lines in a T Tauri spectrum most likely come from?
    - A. Accretion flow
    - B. Slow-moving dust
    - C. Thermal emission
    - D. Protoplanets

25. During this stage in evolution, what would cause the formation of massive protoplanets that are far out and slowly moving in the disk, such as AB Aurigae b?
    - A. Disk instabilities
    - B. Intense magnetic field activity
    - C. Core accretion
    - D. Envelope expulsion

The next three (3) questions discuss a pre-main sequence star, V350 Ori. Image 5 shows a spectrum of V350 Ori in black, and of a non-accreting A-Type star in red.

26. Based on the fit of this spectrum, what type of pre-main sequence object does V350 Ori appear to be?
    - A. T Tauri Star
    - B. Herbig Ae Star
    - C. Herbig Be Star
    - D. Brown Dwarf

27. In this spectral range, what appears to be the primary difference between V350 Ori, which is undergoing accretion, and the non-accreting A-Type star?
    A. Location of spectral lines
    B. Width of spectral lines
    C. Brightness in low-wavelength regions
    D. All of the above
28. Which of the regions in Image 6 is likely the cause of this spectral difference?
    A. Point A
    B. Point B
    C. Point C
    D. Point D

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29. What is the upper limit of the mass of a brown dwarf, in Jupiter masses (M_J)?
    A. $1\,M_J$
    B. $13\,M_J$
    C. $80\,M_J$
    D. $100\,M_J$
30. True or False: Brown dwarfs are formed similarly to stars, through collapse of interstellar medium.
31. In a composite image of an object, consisting of infrared, visible and X-ray radiation, what would brown dwarfs most likely appear as?
    A. Diffuse X-ray regions that don't appear in any other wavelength.
    B. Infrared points that don't appear in visible or X-ray.
    C. Visible points that are surrounded by X-ray halos, and don't appear in infrared
    D. Bright points that appear in all three wavelengths.
32. A researcher observed variability in spectral lines of alkali metals in Luhman 16B. What do we believe is the most likely cause of this?
    A. Changes in cloud cover on the object
    B. Fusion of these metals in the core
    C. Convection of these metals from lower layers
    D. Dust passing in front of the object

The next three (3) questions use the following information. A distant star has an apparent magnitude of $m = 6.39$. Its absolute magnitude is estimated to be $M = -4.38$.

33. [2 pts] Estimate the distance to this star, in parsecs.
    A. 81 pc
    B. 240 pc
    C. 820 pc
    D. 1430 pc
34. this star is also on the main sequence, what would its spectral classification be?
    A. B
    B. F
    C. G
    D. M
35. [2 pts] Gaia is a telescope that has documented properties for thousands of stars. It typically gets the parallax angle to ∼0.04 milliarcsecond precision. What is the parallax angle of this system in arcseconds, and would it be able to be measured by Gaia? Give your answer with 3 significant figures.

Section B: Exoplanets

Unless otherwise specified, each question is worth one points, for a total of 36 points.

"There are infinite worlds both like and unlike this world of ours"
(Epicurus, 341–270 BCE)

The first fourteen (14) questions involve reading a passage and selecting or determining the right word or phrase to complete the blanks, each of which corresponds to a question number.

The light emitted by exoplanets comes from ____(1)____ and ____(1)____ . Direct detection of exoplanets is extremely difficult due to the ____(2)____ star/planet intensity ratio and ____(2)____ angular separation. For instance, suppose you were a civilization located 60 parsecs from the Solar System trying to confirm the existence of Neptune, which orbits at 30 au from the Sun. The star-planet pair would be separated by only ____(3)____ . Astronomers have come up with many alternative exoplanets to detection methods that address these challenges.

1. [2 pts] (Select two answers)
   A. the albedo of its sphere of influence (SOI)
   B. reflected starlight from their host star
   C. atmospheric processes
   D. thermal radiation
   E. occultations with its moons
   F. absorption of stellar irradiance

2. A. high; large
   B. high; small
   C. low; large
   D. low; small

3. A. 2 arcseconds
   B. 1 arcsecond
   C. 0.5 arcseconds
   D. 0.25 arcseconds

Starting with the first discovery a few ____(4)____ ago, astronomers have identified thousands of exoplanets and have discovered a large amount of diversity in their properties. ____(5)____ are gas giants found orbiting close to their stars whereas ____(6)____ are exoplanets classified solely by their mass being higher than Earth's. The discovery of multi-planet systems reveals the importance of ____(7)____ between planets—when they have periods that are a simple integer ratio of each other.

4. A. months
   B. years
   C. decades
   D. centuries

5. A. Ice giants
   B. Compact giants
   C. Fast Saturns
   D. Hot Jupiters

6. A. Super-Earths
   B. Terrestrials
   C. Rocky planets
   D. Kilo-Earths

7. A. secular resonance
   B. rational synchronization
   C. mean motion resonance
   D. orbital coordination

The ____(8)____ observational technique works best on ____(9)____ planets that have a ____(9)____ orbital period (e.g. ____(5)____) and takes advantage of the fact that stars themselves “wobble” slightly as the planet travels around it. This is measured using ____(10)____ as astronomers look at the red- or blueshift of the star’s light.

8. Determine the right word or phrase.

9. A. large; long
   B. large; short
   C. small; long
   D. small; short

10. A. interferometers
    B. spectrographs
    C. astrolabes
    D. bolometers

Another key observational technique is the ____(11)____ method which relies on a periodic dip in brightness—usually on the order of ____(12)____ for giant planets—caused by the planet passing in front of the star. This method is biased towards ____(13)____ planets orbiting ____(13)____ . This method also allows astronomers to discover information about the chemical composition of ____(14)____ .

11. Determine the right word or phrase.

12. A. 0.01 %
    B. 0.1 %
    C. 1 %
    D. 10 %

13. A. large; far
    B. large; close
    C. small; far
    D. small; close

14. A. stellar winds
    B. planetary interiors
    C. planetary surfaces
    D. planetary atmospheres

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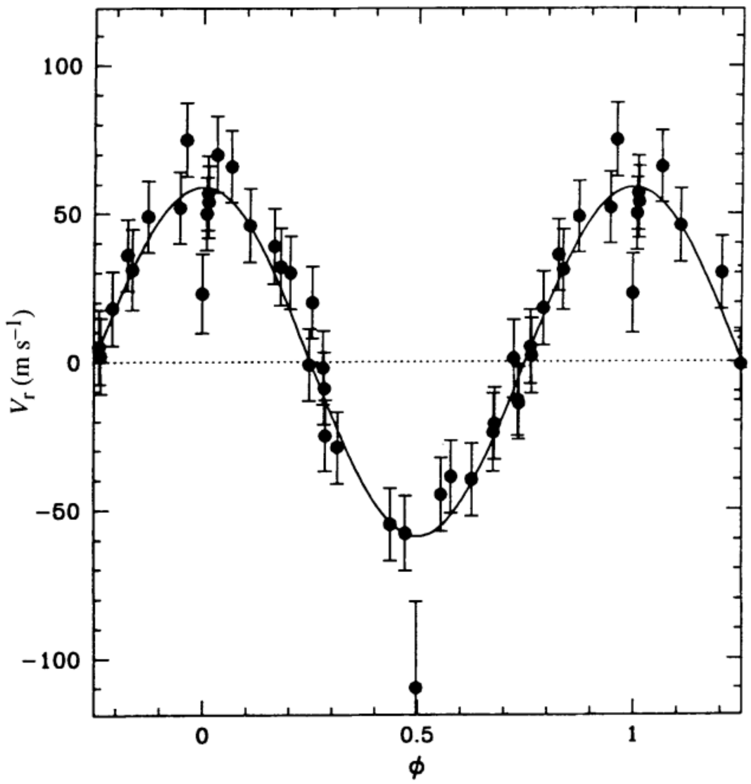
15. [2 pts] Name two exoplanet detection methods beyond the ones listed in the previous passages.

Match the following eight (8) statements with the corresponding exoplanet/planetary system in the list below. Each choice may be used once, more than once, or not at all.

A. V830 Tau b	C. WASP-18b	E. HR 8799	G. 2M 1207
B. V1298 Tau b	D. WASP-39b	F. Beta Pictoris	H. TRAPPIST-1

16. First exoplanet discovered orbiting around a brown dwarf.
17. This object is located around 40 light-years away in the constellation Aquarius.
18. The close orbit of this planet may have resulted in tidal forces that weakens the convection within its host star.
19. A planetary system with two identified exoplanets—one orbiting at 2.7 au and one at 10 au—with the further one with a rotation period a bit over 8 hours.
20. JWST made the first observation of photochemistry occurring in the atmosphere of this exoplanet.
21. KPIC successfully measured the rotation period of three out of the four planets in this star system discovered in 2009.
22. This gas giant exoplanet orbits a host star with the same spectral class as the Sun.
23. The discovery of this hot Jupiter provides support for the inwards migration of giant planets over (relatively) short timescales.

Use the following information and the graph below to answer the next five (5) questions. You observe the orbital motion of a solar-mass star ($M_\star = 1.12\,\mathrm{M_\odot}$) and discover an orbital period of 4.23 d. Note that $1\,\mathrm{M_\odot} = 1.99 \times 10^{30}$ kg. Assume that the star is observed exactly edge-on, the entire system has circular orbits, and that the mass of the host star $M_\star$ is much greater than the mass of the planet M_p (i.e. $M_\star \gg M_\mathrm{p}$).



24. Use the graph to determine the semi-amplitude of the fitted sinusoid in $\mathrm{m\,s^{-1}}$. Round to the nearest tens (e.g. $12\,\mathrm{m\,s^{-1}}$ would round to $10\,\mathrm{m\,s^{-1}}$).

25. Where would you expect the barycentre of the star-planet system to be located?
    - A. Halfway between the star and the planet
    - B. Closer to the star than the planet
    - C. Closer to the planet than the star
    - D. At the center of the star

26. [2 pts] Calculate the semi-major axis of the orbit of the star around the barycentre $a_\star$ in au. There are 1.50×10^{11} m in 1 au. Give your answer with 3 significant figures.

27. [3 pts] Finally, use Kepler's third law to determine the mass of the exoplanet in Jupiter masses ($1\,\mathrm{M_J} = 1.90 \times 10^{27}$ kg). It may be helpful to know the gravitational constant $G = 6.67 \times 10^{-11}\,\mathrm{N\,m^2\,kg^{-2}}$.

28. [4 pts] (Free Response) One useful metric for assessing exoplanets is by looking at its mean density. Explain how you could determine the density of this planet starting from the information you already know from the past 4 questions. Points that you should hit are: (1) what sort of data would you need to collect, (2) what parameters would you be able to determine from the data, and (3) what formulas would you use in the process of finding the planet density.